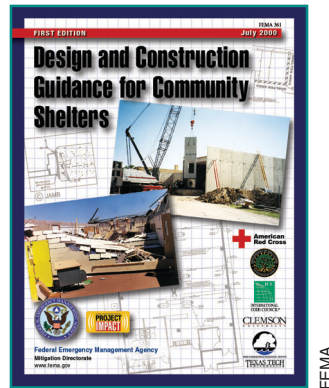


Selection Procedure



Guidance for Refuge Area Selection

Detailed evaluation checklists for selecting the best available refuge areas in existing buildings and guidance for designing and constructing shelters are presented in FEMA 361, *Design and Construction Guidance for Community Shelters* (for more information, see the section of this booklet titled **Information Sources**.)

The procedure presented in this chapter is designed to assist in a systematic review of a building for the purpose of selecting the areas within the building that are likely to be the most resistant to tornadoes, referred to in this booklet as the **best available refuge areas**. When used for refuge during tornadoes, these areas do not guarantee safety; they are, however, the safest areas available for building occupants. This selection procedure does **not** apply to structures such as lightweight modular houses and offices and relocatable classrooms. Such structures are presumed to fail, and **they must be evacuated**.

Most buildings, unless specifically designed as shelters, will sustain catastrophic damage if they take a direct hit from a Violent Tornado (i.e., a tornado ranked F4 or F5 on the Fujita Tornado Damage Scale—see Chapter 1). Because the maximum wind speeds associated with a Violent Tornado greatly exceed the wind speeds that the buildings were designed to withstand, complete destruction will usually occur during these extremely rare events.

In reality, most tornadoes do not produce the winds of a Violent Tornado, and some areas of many buildings can survive these lesser events without catastrophic damage or collapse. Placing building occupants in the **best available refuge areas** within a building greatly reduces the risk of injury or death. However, unless the refuge area was designed as a shelter, its occupants are vulnerable to injury or death.

Selecting the **best available refuge areas** involves three main steps:

- **determining how much refuge area space is required** to house building occupants

- **reviewing construction drawings and inspecting the building** to identify the strongest portion(s) of the building
- **assessing the site** to identify potential tree, pole, and tower fall-down and windborne missiles

Determining the required refuge area space and assessing the site are relatively straightforward tasks that can be completed by many people. The drawing review and building inspections are more technical in nature. Qualified structural engineers or architects should be consulted for those tasks.

Determine the Required Amount of Refuge Area Space

Refuge areas must be large enough to provide space for all occupants who may be in the building when a tornado strikes. In schools, space must be provided for all students and faculty, maintenance and custodial workers, and any parents or other visitors who may be present.

Refuge area space requirements vary according to the age of the occupants and any special needs they may have. FEMA publication 361, *Design and Construction Guidance for Community Shelters*, recommends that shelter space determinations be based on the following guidelines:

Children Under 10	5 square feet per person ¹
Adults, Standing	5 square feet per person
Adults, Seated	6 square feet per person
Wheelchair Users	10 square feet per person
Bedridden Children or Adults	30 square feet per person

¹ Previous editions of this booklet recommended 3 square feet per person for small children.

Example Calculation of Required Refuge Area Space

Consider an elementary school that has 560 students, 2 of whom use wheelchairs; 28 faculty members; and 3 custodial and maintenance workers. Calculating the required refuge area space involves identifying all groups of occupants and their refuge space needs:

558 Children @ 5 sq ft each	= 2,790 sq ft
31 Adults @ 6 sq ft each	= 186 sq ft
2 Wheelchair users @ 10 sq ft each	= 20 sq ft

Total = 2,996 sq ft

In this instance, the required refuge area space could be provided by a total of 375 feet of 8-foot-wide corridor or by a combination of smaller areas.

In larger buildings, several dispersed refuge areas should be selected when possible so that travel times for building occupants are minimized. Keep in mind that building occupants with special needs, such as wheelchair users, may require additional time to reach the refuge area.

Review Construction Drawings and Inspect the Building

As there are stronger and weaker tornadoes, there are stronger and weaker portions of any building. The construction drawing review and building inspection help identify the stronger areas that are most resistant to damage from high winds and windborne missiles.

Selecting the best available refuge areas involves predicting how a building may fail during an event that produces complex winds and unpredictable missiles. The failure modes in a building are numerous, complex, and progressive. The complex nature of tornadoes and the variations in as-built construction limit the effectiveness of even detailed engineering models in accurately predicting failure of an existing building. However, experience and subjective judgment can help identify areas that are less prone to failure during a tornado.

Protective Elements

The **lowest floor** of a building is usually the safest. Upper floors receive the full strength of the winds. Occasionally, tornado funnels hover near the ground but hit only upper floors. **Belowground space** is almost always the safest location for a refuge area. If a building has only one floor and no basement, look for building elements that can improve the chances for occupant survival:

1. **Interior partitions** that provide the greatest protection are somewhat massive, fit tightly to the roof or floor structure above, and are securely connected to the floor or roof. Avoid interior partitions that contain windows.

Why Are Individual Building Inspections Needed?

This section describes the role of different building elements in providing safety from extreme winds. However, individual buildings can vary considerably; therefore, individual building assessments based on the guidelines of FEMA publication 361 are always recommended. For example, although the lowest floors in a building are usually the safest, an individual evaluation of a school building may find that second-story areas are safest in a particular instance. Another example, shown previously, is the performance of Kelly Elementary School. Although interior corridors are often one of the safer areas, the corridors in Kelly Elementary School, as originally constructed, were unsafe during the F4 tornado that struck Moore, Oklahoma. An individual evaluation of Kelly Elementary School using the checklists in FEMA 361 would reveal these weaknesses.

2. **Short spans** on the roof (see sidebar) or floor structure are more likely to remain intact. This is because short spans limit the amount of uplift on connections caused by winds. Although short spans are best, small rooms, even those with walls that do not support the roof, may be the best available refuge areas. If the roof rises and then collapses, the interior walls may become supporting walls and thereby protect the occupants, although there is the risk that the walls will also collapse or be blown away.
3. Buildings with **rigid frames** usually remain intact. Buildings with heavy steel or reinforced concrete frames rigidly connected for lateral and vertical strength are superior to buildings that contain loadbearing walls. On the other hand, wood-framed construction used in residences and in light commercial buildings can be extremely vulnerable to damage from high winds. Wood-framed and pre-engineered metal buildings should not be used as tornado shelters.
4. **Poured-in-place reinforced concrete, fully grouted and reinforced masonry**, and **rigidly connected steel frames** are usually still in place after a tornado passes. However, in either type of construction, the floor or roof system must be securely connected to the supports. Gravity connection of the roof deck to the frame is inadequate. Generally, the heavier the floor or roof system, the more resistant it is to lifting and removal by extreme winds. Figure 4-1 shows typical fully grouted, reinforced masonry wall construction.

Hazardous Elements

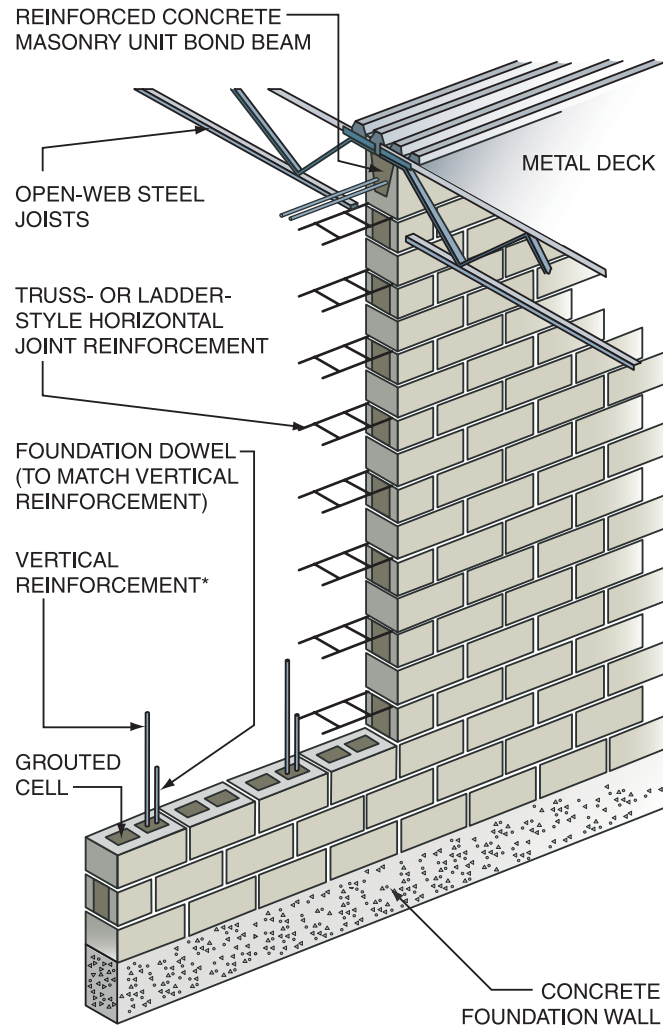
The following building elements seriously diminish occupant safety. Areas that contain these elements should not be used as refuge areas.

1. **Long-span roofs** are almost always found on rooms with high ceilings (e.g., gyms, auditoriums, music and multipurpose rooms). The exterior walls of such rooms are higher than typical one-story walls and often collapse under the forces imposed by tornado winds. Occasionally, high

What is a Short-Span Roof?

No single number defines a “short span.” The ability of any roof to resist wind uplift depends on several factors. The type of structural members used in the roof (e.g., steel joists vs. reinforced concrete frames), the weight of the roof (heavy for concrete decks vs. light for most metal decks), and the strength of the connections between the roof and the supporting structure all dictate how well a roof will resist high winds.

In FEMA publication 342, *Midwest Tornadoes of May 3, 1999*, FEMA’s Building Performance Assessment Team recommended that rooms with roof spans longer than 40 feet not be used as refuge areas. Similarly, the Red Cross limits roof spans to 40 feet for hurricane shelters. The 40-foot criterion should be considered an absolute maximum unless an engineering analysis determines that the roof system is adequate. Preferably, best available refuge areas should have roof spans that are 25 feet or less.



* SPACING OF VERTICAL REINFORCING BARS IN MASONRY WALLS VARIES AND IS CONTROLLED BY FACTORS SUCH AS WALL HEIGHT, WALL WIDTH, AND DESIGN WIND SPEED.

Figure 4-1
Typical fully grouted, reinforced masonry construction.

walls collapse into a long-span room, and roofs that depend on the walls for support collapse. Building administrators must resist the temptation to gather many building occupants into a large space so that control will be easier. **Often these spaces incur maximum damage; if a large group of people is present, many deaths and injuries are likely to result.**

2. **Lightweight roofs** (e.g., steel deck, gypsum, lightweight insulating concrete, cement woodfiber, wood plank, and plywood) usually will be lifted and partially carried away while roof debris falls into the room below. The resulting opening then allows other flying debris to be thrown into the interior space. In addition, walls often collapse after loss of the roof deck.
3. **Heavier roofs** (e.g., precast concrete planks, channels, and tees) may be lifted, move slightly, and then fall. If supporting walls or other members have collapsed, the roof may fall onto the floor below, killing or seriously injuring anyone there. Cast-in-place concrete decks typically remain in place.
4. **Windows** are no match for the extreme winds or missiles of a tornado. Windows usually break into many jagged pieces and are blown into interior spaces. Even tempered glass will break, but usually into thousands of small, cube-like pieces. Windows in interior spaces also break, usually from missile impact. Acrylic or polycarbonate plastics are more resistant to impact than glass, but large panes may pop out, and the fumes given off when these materials burn can be toxic. Laminated glass can be quite effective, except when hit by very powerful missiles (see Figure 3-22, in Chapter 3). Windows at the ends of corridors are particularly dangerous because high winds can blow them down the corridor. (See window protection sidebar on page 42.)
5. **Wind tunnels** occur in **unprotected corridors** facing oncoming winds. In post-event damage inspections, debris marks have been found covering the full height of corridor walls, indicating that the winds occupied almost the entire volume of the corridor. If entrances are baffled with a solid, massive wall, this effect is much less serious.

6. **Loadbearing walls** are the sole support for floors or roofs above. If winds cause the supporting walls to fail, part or all of the roof or floors will collapse. In addition, walls often collapse after loss of the roof deck.
7. **Masonry construction** is not immune to wall collapse. Most masonry walls are **not vertically reinforced** and can fail when high horizontal forces such as those caused by winds or earthquakes occur. Masonry walls without vertical reinforcement are potentially hazardous. Such walls can also fail and create an additional hazard if the roof deck is lost.

Assess the Site

Inspect the site and identify trees in excess of 6 inches in diameter, poles (e.g., light fixture poles, flag poles, power poles), masonry chimneys, and towers (e.g., electrical transmission and communication towers). Those trees, poles, chimneys, and towers that are close enough to fall on the building should be marked on a site plan. Accurately locate those trees, poles, chimneys, and towers and note the approximate height of each on the plan. (An example of a site plan is shown in the refuge area selection example presented later in this chapter.)

In selecting the best available refuge areas, plot the tree, pole, chimney, and tower fall-down areas on the building plan. The best available refuge area should not be located within or adjacent to the fall-down areas, because fall-down of trees, poles, chimneys, and towers can cause localized building collapse (see Figures 4-2 and 4-3). In addition to falling, these elements can also be blown a considerable distance (see Figure 4-4).

For most building locations, there will be many nearby sources of small and large windborne missiles. Missile examples include aggregate roof surfacing, rooftop HVAC equipment, components from nearby damaged buildings (e.g., roof decking, studs, joists, trusses, hot water heaters, kitchen appliances, building furnishings), tree limbs, trees, trash containers, propane tanks, poles,

A Note About Window Protection

Many facilities in hurricane-prone areas have provisions to protect vulnerable windows from high winds and windborne debris. Most window protection methods are designed for wind speeds much lower than those associated with tornadoes. Also, some window protection devices, such as shutters and storm panels, need to be installed or closed to offer any benefit. With tornadoes, there will generally not be sufficient warning time for this to be accomplished. Consequently, any refuge area with large windows should be avoided.

An evaluation of potential refuge areas may include areas with doors that contain small windows. After an evaluation has been completed, areas that include such doors could still be considered the best available refuge areas despite the vulnerability of the glass. However, known problems should be addressed to the extent possible. Examples of corrective actions that could be taken include replacing any doors that contain windows, replacing the existing glazing with more impact-resistant glazing, and ensuring that the occupants of the refuge area are not in the path of any debris that could be generated by the failure of these small windows.

Figure 4-2

Two trees toppled by tornado winds damaged this house in Haysville, Kansas.



FEMA

Figure 4-3

Failure of brick chimney under tornado winds damaged the room of this house in Moore, Oklahoma.



FEMA



automobiles, buses, and trucks. Missiles can be propelled horizontally and vertically (see Figures 2-2, 2-3, 2-4, and 4-5). Therefore, in selecting the best available refuge areas, it is typically prudent to assume that the building being evaluated will be bombarded with both small and large missiles, traveling horizontally and vertically.

Example of Refuge Area Selection Process

The following example illustrates the methodology for assessing refuge area needs and identifying the best available refuge areas.

General

The example facility is a single-story elementary school built in the early 1990s. In layout, design, and construction, it is typical of many schools in

Figure 4-4

This power pole penetrated a window and extended several feet into the house after being blown 40 feet from its original location.



Figure 4-5

This photograph illustrates the importance of overhead protection in refuge areas. The missile shown here fell nearly straight down.

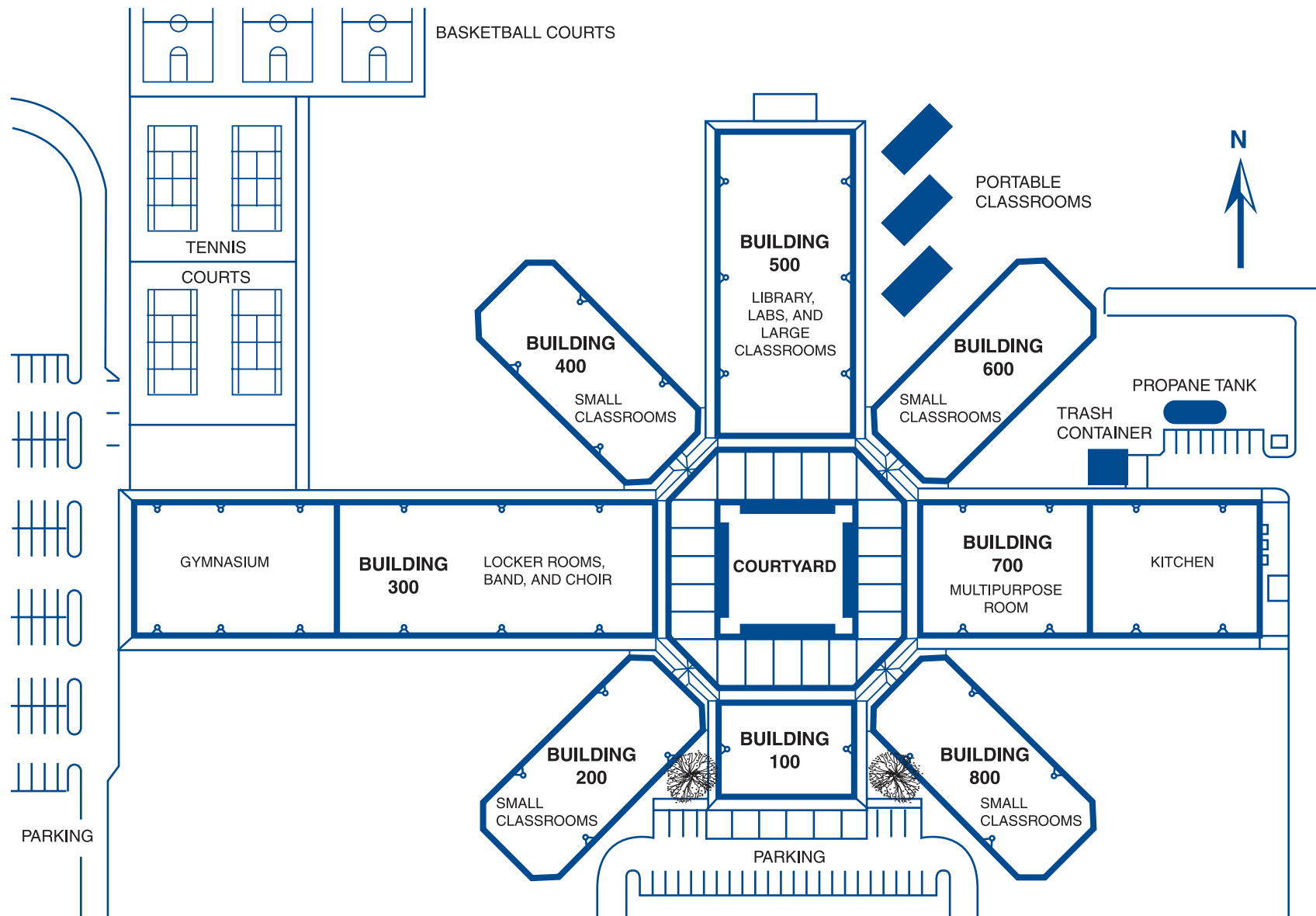


Figure 4-6 Site plan for example facility.

Florida. As shown by the site plan in Figure 4-6, the school consists of eight separate wings (Buildings 100–800) situated around a central courtyard. The school site includes parking areas to the west and south, several wood-framed portable classrooms near the library, a tall flagpole in the courtyard, and a trash container and aboveground propane tank near the kitchen.

The school population comprises 1,146 students, 49 faculty and administrative staff, and 3 maintenance workers and custodians. One of the students uses a wheelchair.

Required Refuge Area Space

The following is a calculation of the required refuge area space for the population of this example school based on the guidelines in FEMA publication 361, *Design and Construction Guidance for Community Shelters*.

1,145 Children @ 5 sq ft each	= 5,725 sq ft
52 Adults @ 6 sq ft each	= 312 sq ft
1 Wheelchair user @ 10 sq ft each	= 10 sq ft
Total = 6,047 sq ft	

Architectural and Structural Characteristics

Building 100 is the main entrance to the school. It is much smaller than the other buildings and contains the administrative offices. Building 300 contains the gymnasium, locker rooms, and the band and choir areas. The library, labs, and other large classrooms are in Building 500. The kitchen and multi-purpose room (a cafeteria that doubles as an auditorium) are in Building 700. Figure 4-7 shows the floor plan of Building 500. The general layouts of Buildings 100, 300, and 700 are similar to that of Building 500.

Buildings 200, 400, 600, and 800 contain typical classrooms. These classrooms are smaller than the library, labs, and large classrooms in Building 500 and, unlike the rooms in Buildings 100, 300, 500, and 700, are accessed from long, central, interior corridors. Figure 4-8 shows the floor plan

Figure 4-7
Floor plan of Building 500.

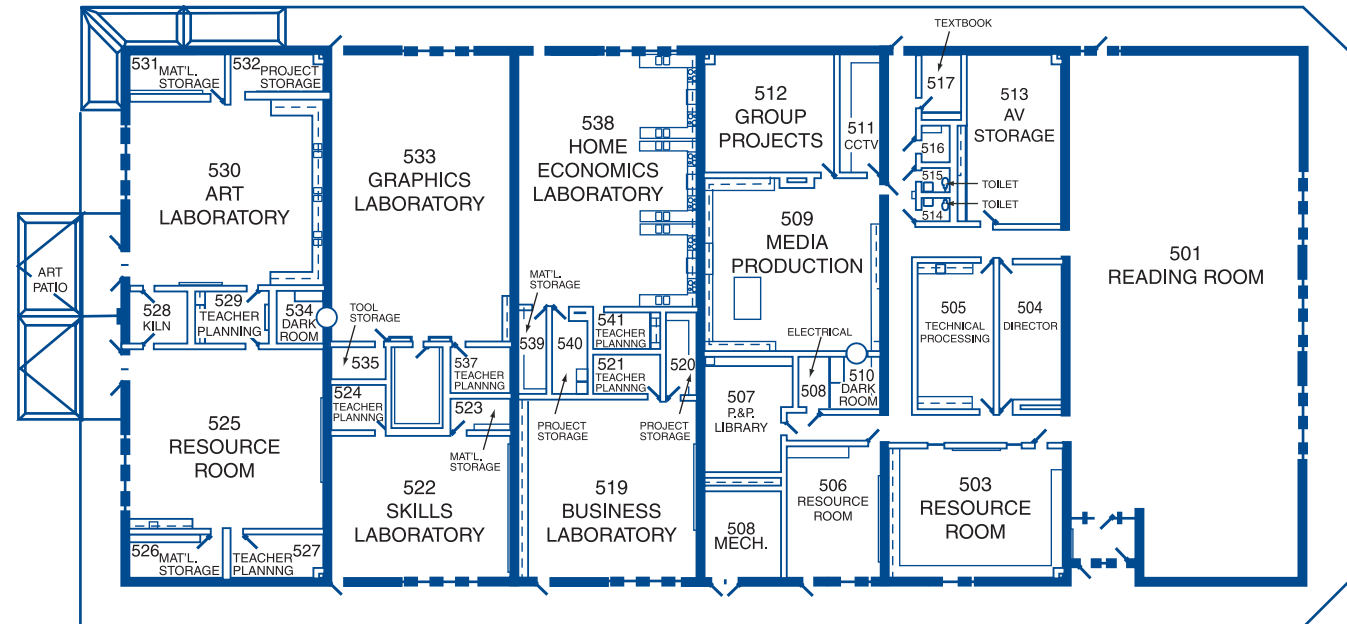
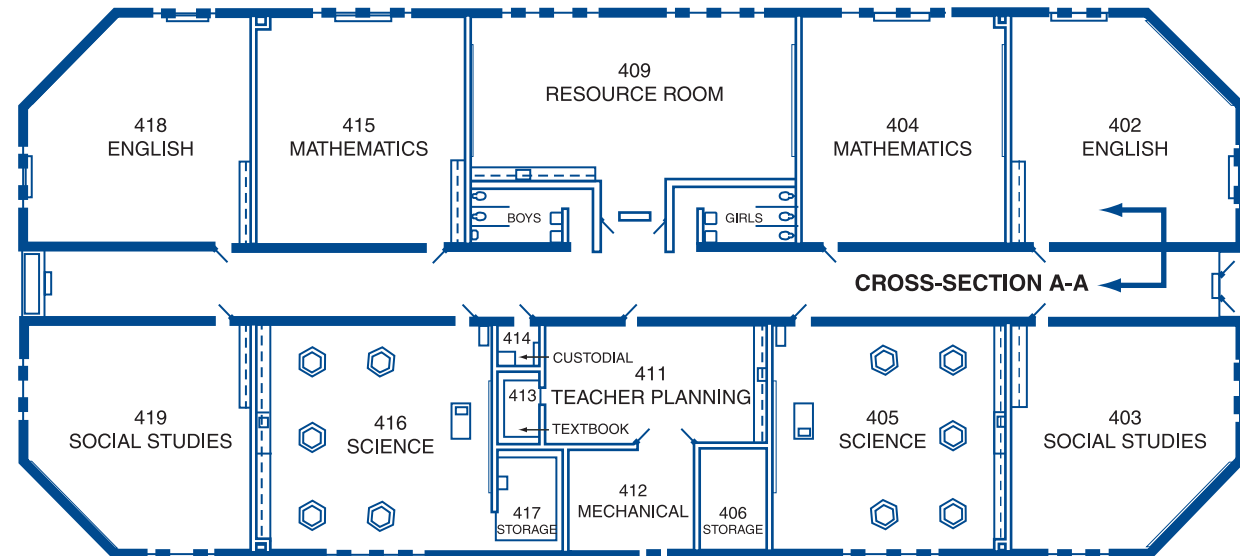


Figure 4-8
Floor plan of Buildings 200, 400, 600, and 800 (see Figure 4-10 for the wall cross-section at A-A).





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Figure 4-9
Interior central corridor – typical of the corridors in Buildings 200, 400, 600, and 800.

of Buildings 200, 400, 600, and 800. One of the central corridors in these buildings is shown in Figure 4-9.

In each of the eight buildings, exterior and interior loadbearing concrete block masonry walls support the roof above. These walls are reinforced with vertical steel spaced at 2 feet 8 inches on center. Figure 4-10 shows a cross-section of one of the loadbearing corridor walls in Buildings 200, 400, 600, and 800 (the location of this cross-section is shown in Figure 4-8). The exterior walls include a brick veneer that is relatively resistant to the impact of small wind-borne debris. The interior partition (non-loadbearing) walls are unreinforced masonry, extend only 6 inches above the suspended ceilings, and are not laterally secured to the roof.

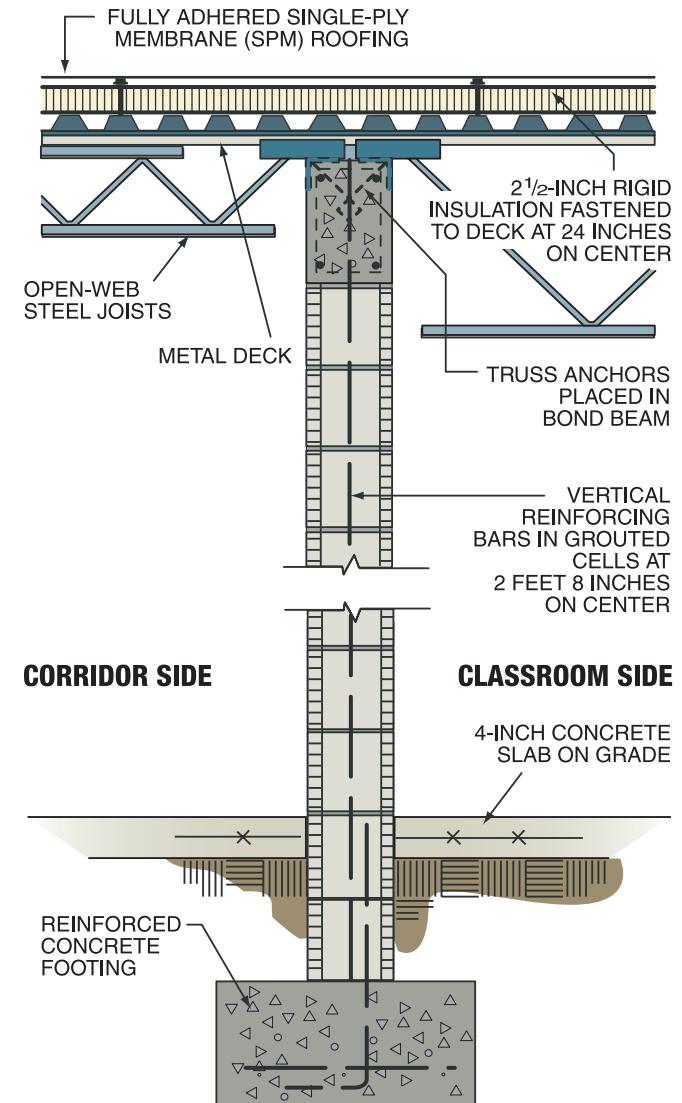


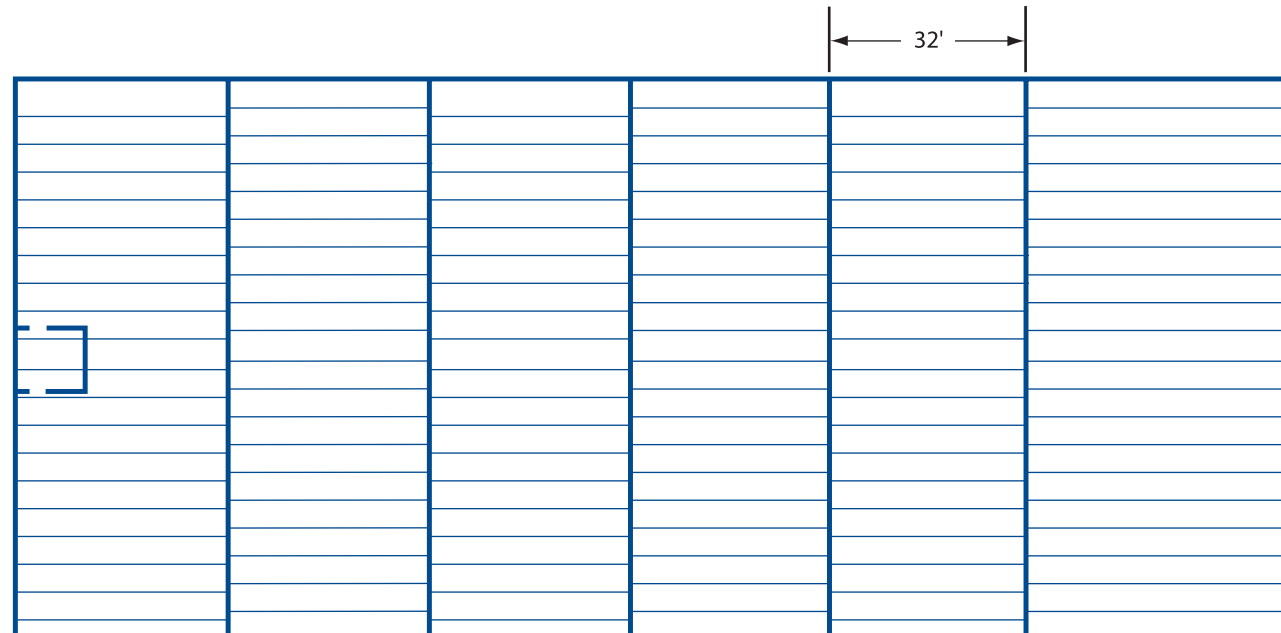
Figure 4-10
Cross-section A-A through corridor/classroom wall – Buildings 200, 400, 600, and 800 (see Figure 4-8 for location of A-A).

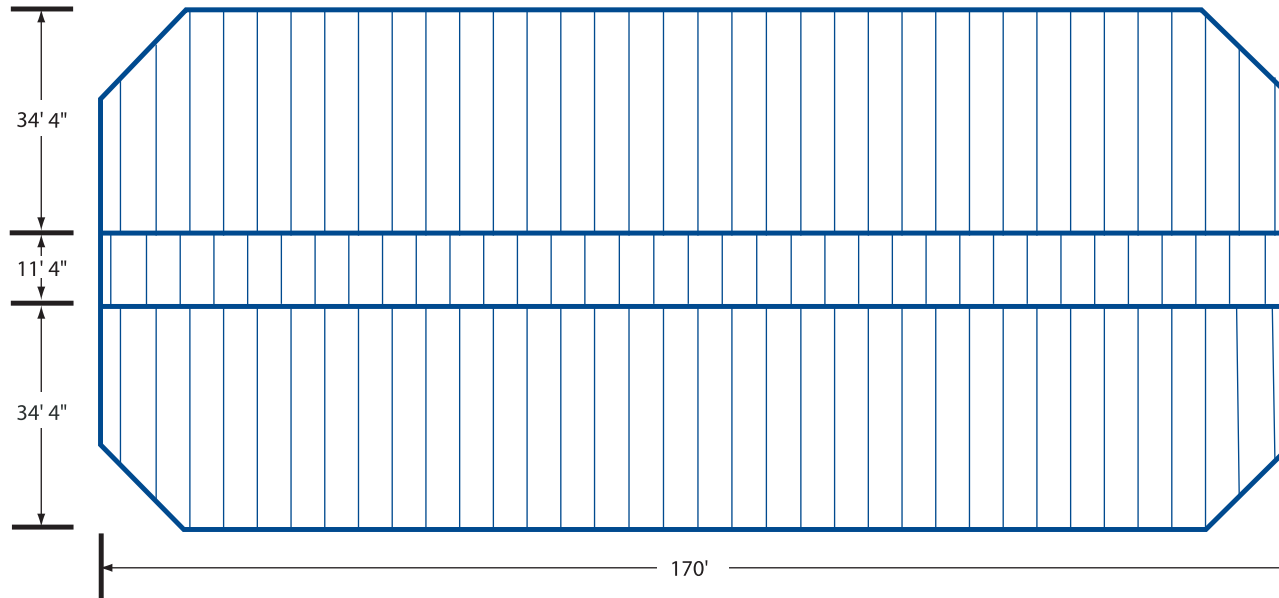
Note that a visual inspection of structure walls will **not** reveal whether or how they are reinforced. Construction drawings will show whether the wall design includes reinforcement and will provide details regarding the intended size and placement of reinforcing steel. However, only an inspection of the interior of a wall will reveal the actual construction. Such inspections can be made with nondestructive tests (e.g., magnetic, ultrasonic, or x-ray).

The roofs of the eight buildings are relatively lightweight and are constructed with open-web steel roof joists, metal decking, rigid insulation, and single-ply membrane roofing. In Buildings 300, 500, and 700, the roof framing typically spans 32 feet between the supporting loadbearing walls (Figure 4-11). The roof framing in Building 100 is similar.

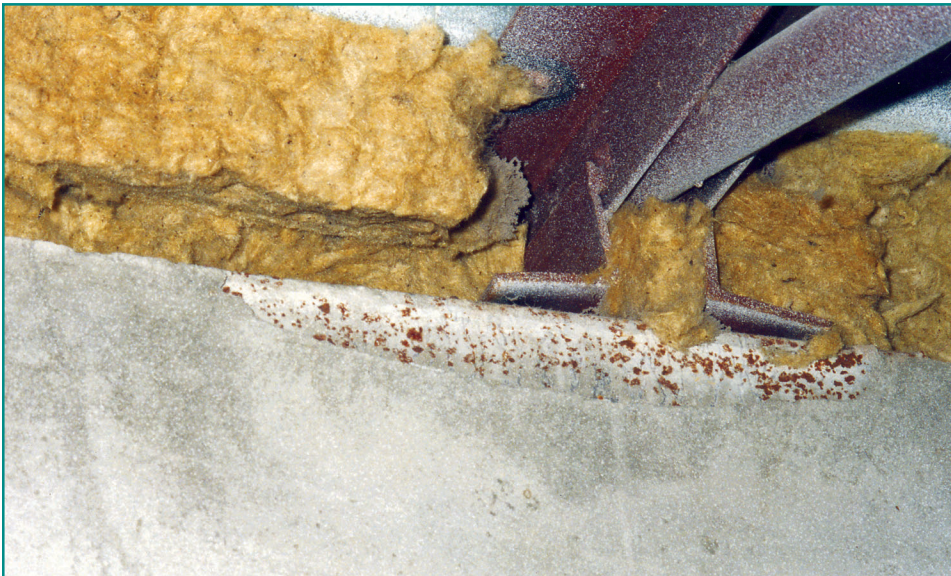
In Buildings 200, 400, 600, and 800, the roof framing spans 34 feet 4 inches from the exterior loadbearing walls to the center loadbearing corridor walls.

Figure 4-11
Roof framing plan for
Building 500.





*Figure 4-12
Roof framing plan for
Buildings 200, 400, 600,
and 800.*



*Figure 4-13 Typical roof truss connection to exterior
wall in the example school.*

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Separate roof joists span the 11-foot 4-inch-wide corridors (Figure 4-12). In all eight buildings, the roof joists are fastened to the tops of the masonry load-bearing walls with welded base plates and anchor bolts (Figure 4-13).

The exterior windows in all eight buildings have aluminum frames and tempered glass. The exterior doors—including the exterior corridor doors in Buildings 200, 400, 600, and 800 (Figure 4-14)—are insulated metal-framed units with large windows. The doors from the corridors to the classrooms in these four buildings are wood with small windows (Figure 4-15).

Identifying the Best Available Refuge Areas

In the identification of the best available refuge areas, several locations were ruled out because of their limited strength, inherent weaknesses, or lack of usable space.

Figure 4-14
Exterior corridor doors in the example school.





Figure 4-15

Door connecting classroom to corridor – Buildings 200, 400, 600, and 800.

Buildings 300, 500, and 700 were ruled out for two reasons:

1. **Vulnerability to debris impact and wind penetration.** These buildings contain many large exterior windows that are extremely vulnerable to penetration by windborne debris. As noted in Chapter 2, once the building envelope is breached, wind enters the building and the pressures on the building increase. In addition, debris can enter the building through the window openings and may injure or kill building occupants.
2. **Long roof spans.** As noted earlier, the roof spans in these buildings are 32 feet long. Long-span roofs are more susceptible to uplift, which can lead to the collapse of the supporting walls.

Building 100 was also ruled out. In addition to sharing the vulnerabilities of Buildings 300, 500, and 700, Building 100 is relatively small, as are the rooms it contains. The available space in this building is further restricted by the large amount of furniture and office equipment normally found in an administrative building.

The interior corridors in Buildings 200, 400, 600, and 800 (Figure 4-16) offer the best available refuge areas in this example. The corridors have relatively short roof spans and relatively small percentages of exterior window glass. In addition, because the classroom doors open onto the corridors, the occupants of these buildings would have ready access to these refuge areas.

Each corridor is 10 feet 8 inches wide (11 feet 4 inches minus the 8-inch wall thickness) and 170 feet long, and provides approximately 1,800 square feet of **gross refuge area space**. Assuming that a 2-foot-wide clear area must be

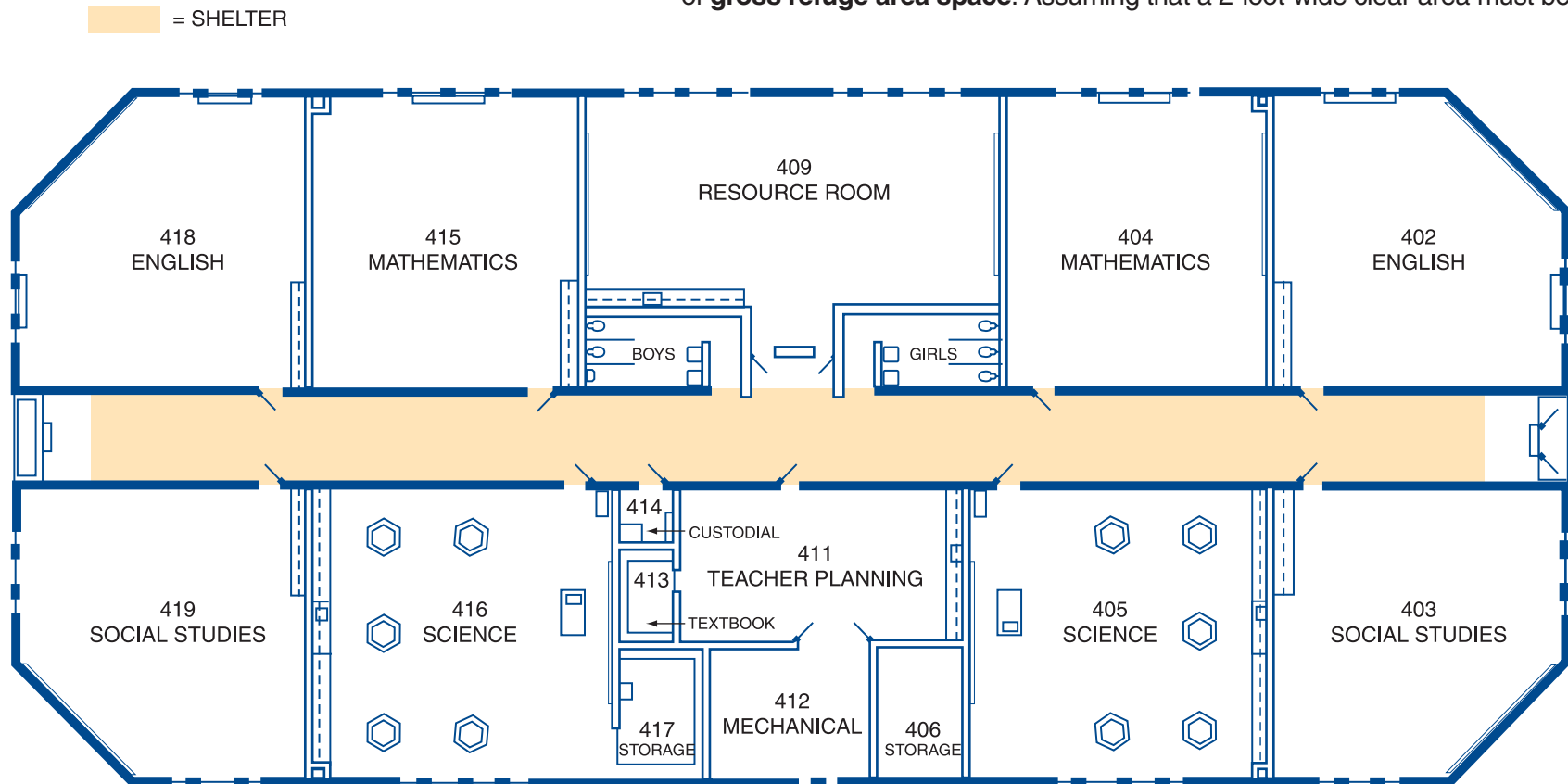


Figure 4-16 Best available refuge areas in the example school – corridors in Buildings 200, 400, 600, and 800.

maintained to allow students and staff to access the refuge area, each corridor can provide approximately 1,500 square feet of **usable refuge area space**. The four corridors provide 6,000 square feet of usable refuge area. While slightly less than the recommended total of 6,047 square feet, the available usable refuge area space satisfies the intent of FEMA publication 361.

Although these corridors are the best available refuge areas in this example, they could be made more resistant by the construction of a wind-resistant alcove that would protect the exterior glass doors and help prevent the entry of wind and debris into the refuge area (Figure 4-17). An alternative would be to install solid, wind-resistant exterior doors that, although normally left open, could be closed when a tornado warning is issued. A less desirable option would be to add a double set of laminated glass exterior doors.

Building administrators and school officials must weigh the protective benefits of such modifications against potential security problems, in the case of solid-wall alcoves, and the need for adequate warning time, for the operation of protective doors. An upgrade alternative for the interior corridor doors would be to replace them with stronger doors equipped with stronger hardware and small laminated glass windows.

In many buildings, the size of the best available refuge area will be less than the required size determined according to the guidelines in FEMA publication 361. In such buildings, the occupants will need to be housed in either smaller areas or more vulnerable areas. Although there are physical limits to the number of people a space can accommodate, housing more people in less space is preferable to locating them in more vulnerable areas.

Verifying the Best Available Refuge Areas

After refuge areas have been selected according to the methodology described in this chapter, the evaluation checklists in FEMA publication 361 should be used to verify that the selected areas are the best available in the building. FEMA 361 also includes information that can help building adminis-

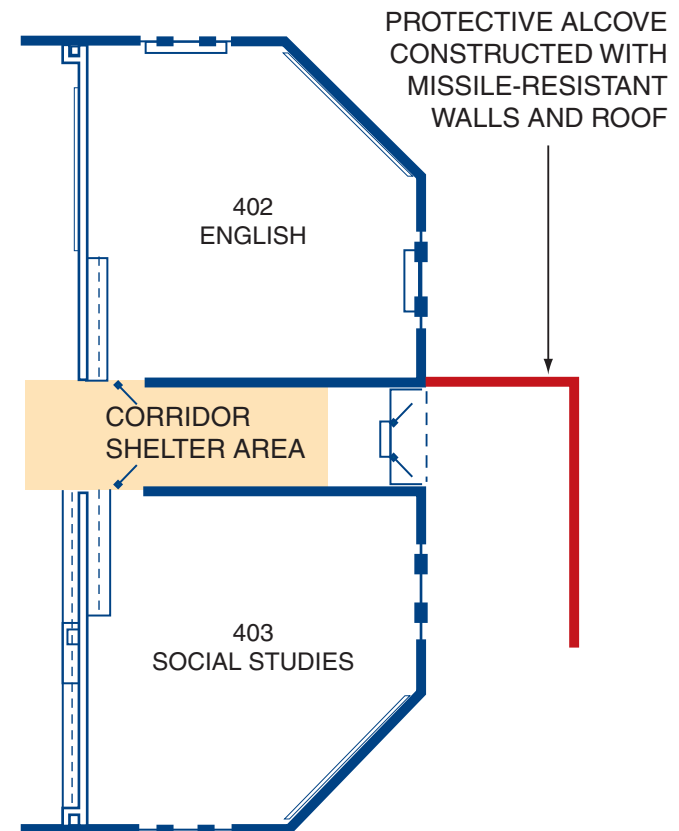


Figure 4-17
Glass exterior doors can be protected from wind and debris with a wind-resistant alcove.

trators improve the effectiveness of the selected refuge areas (e.g., guidelines concerning signage and operations plans).

Selecting the Best Available Refuge Areas in Other Types of Buildings

Mid-Rise and High-Rise Buildings

In buildings with more than five stories, the building frames receive custom structural engineering analysis and design attention. Experiences of the past 50 years indicate that these buildings do not collapse under wind loads, but the outside walls and roof structure can receive major damage. The best available refuge areas in these buildings are in the lower floors (basement if available) and in the central part of the building. Stairwells (particularly those with reinforced concrete walls) typically provide the best available refuge. If the stairwells have inadequate capacity for the occupant load, restrooms typically provide the next best available refuge areas.

Large Stores and Movie Theaters

In large stores and movie theaters, the best available refuge areas will typically be restrooms, closets, or narrow storage areas. For example, in 2002, in Van Wert, Ohio, 50 people in a movie theater took refuge in restrooms when warned about an approaching tornado. The building collapsed, but no one suffered significant injury. In grocery stores, if restrooms, closets, or narrow storage areas are not accessible, building occupants should crouch in narrow frozen food aisles between freezer cases and cover their heads. This tactic will reduce the likelihood of injuries from a falling roof. The aisles used should be as far as possible from exterior glass and masonry walls. Also, aisles with very tall storage racks should be avoided.

Again, the selection of refuge areas should always be verified with the checklists provided in FEMA publication 361.